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AUTHOR	Knapp, Henry H., III
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ABSTRACT

This module on solar system economics is one of six in a series intended for use as supplements to currently available materials on solar energy and energy conservation. Together with the recommended texts and references (sources are identified), these modules provide an effective introduction to energy conservation and solar energy technologies. The module is divided into these sections: (1) set of objectives; (2) programed instructional material, consisting of short readings describing ideas and techniques one step at a time, and a question or problem on each reading; (3) review questions and answers at intervals; and (4) posttest. Objectives for this module are for the student to be able to discuss major ideas involved in life cycle costing of combination solar and conventional heating systems and compare life cycle costs of conventional and combination solar/conventional heating systems. (YLB)

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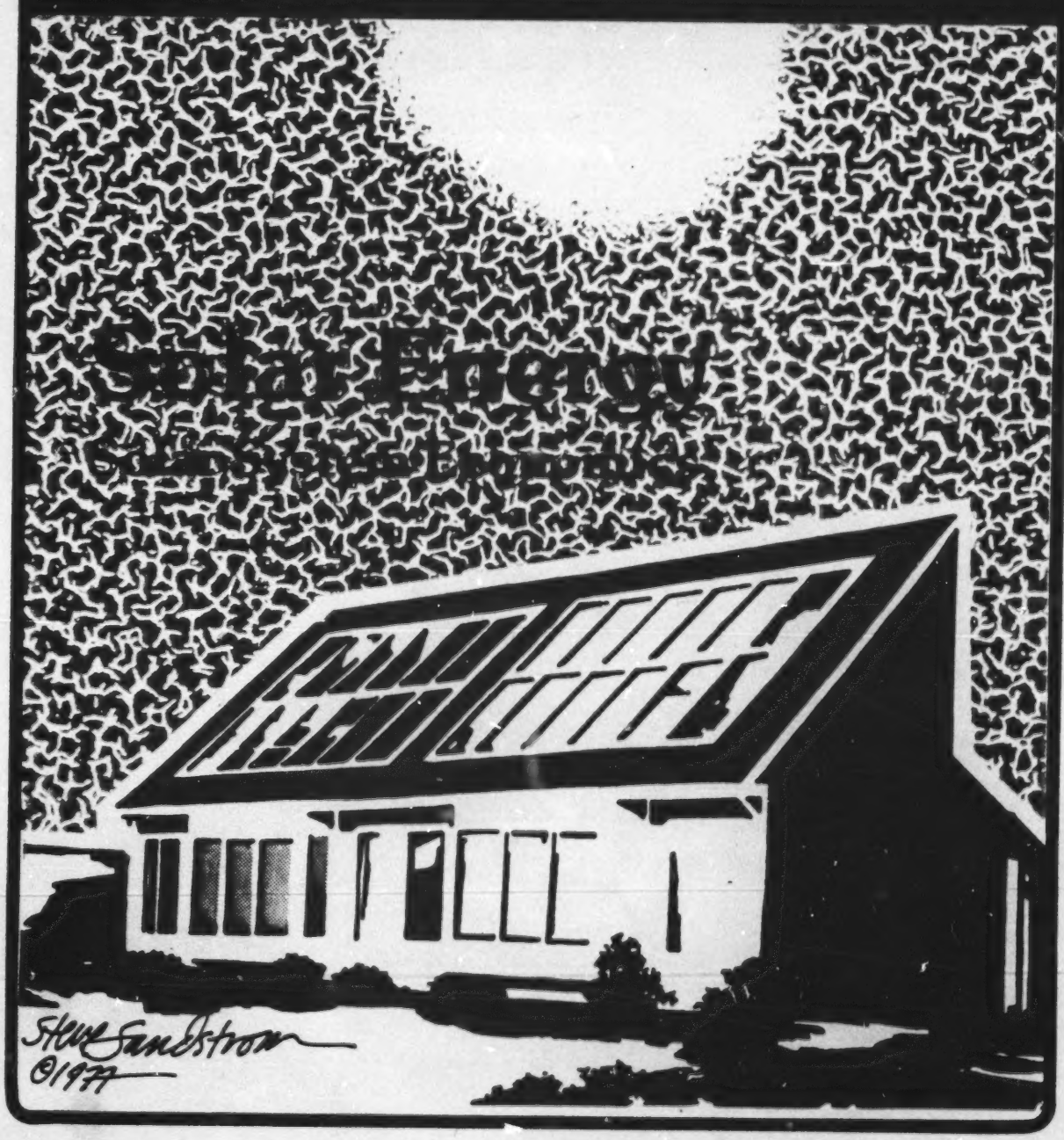

INSTRUCTIONAL LEARNING SYSTEMS

Solar Energy

Writer:
Henry H. Knapp III, Instructor
Linn-Benton Community College

Specialists:
Howard Brock, Conservation
Don Austen, Curriculum
Oregon Department of Education

Coordinator:
James W. Hargis, Curriculum
Oregon Department of Education

Host Institution:
Linn-Benton Community College

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Introduction

These modules are intended to be used as supplements to currently available materials on solar energy and energy conservation. The two best available texts are

Leckie, Masters, Whitehouse and Young; Other Homes and Garbage, Sierra Club Books, 1975

and

Anderson, The Solar Home Book, Cheshire Books, 1975.

There are several reference works that would also be very useful to have on hand. The three most useful ones are

ASHRAE Guide and Data Book, Handbook of Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1977.

U.S. Department of Commerce, Climatic Atlas of the United States, Environmental Data Service, Reprinted by the National Oceanic and Atmospheric Administration, 1974.

U.S. Department of Commerce, Monthly Normal of Temperature, Precipitation and Heating and Cooling Degree-Days (1941-1970) National Oceanic and Atmospheric Administration, Climatography of the United States (by state).

The last two references can be obtained from the National Climatic Center, Environmental Data Service, Federal Building, Asheville, NC 28801. The most important data to have on hand are the percent possible sunshine and heating degree-day records for locations in Oregon. They're available in the last two references. Some data are also available in the two texts and the modules themselves.

The modules are designed to simplify and supplement the treatment of some of the subjects discussed in the texts and references. In combination, the modules, texts, and references provide an effective introduction to energy conservation and solar energy technologies.

The technique you'll use to learn the skills presented in this module is called programmed instruction. It's a technique which we think will enable you to learn these new skills quickly and easily.

The module is divided into several sections:

1. A set of objectives, which tells you what you should expect to learn from this module.
2. Programmed instructional material which we'll describe later on in this introduction.
3. A post-test, which will help you find out what you were able to learn by using the module.
4. A student evaluation form which you can use to tell us what you liked and disliked about the module, so we can make it better for students who use it later on.

The programmed part of the module consists of short readings which show you the ideas and techniques you need a step at a time. Most are followed by a question or problem which gives you a chance to review what you just read. Depending on your answer to the question or problem, you'll be guided to another short reading which will either help you review a little more, or introduce you to a new idea or technique. Each short reading is called a frame.

To get the most out of the programmed part, you need to follow the directions exactly. Resist any temptations to skip around, and respond in the best way you can to the question in each frame before moving on to the frame you're told to read next.

It'll help to have pencil, paper, and a pocket calculator handy for some of the computations you're asked to do.

Don't forget about your instructor. You don't have to do it all by yourself. Ask for help with any part of the module that you can't get through by yourself. Good luck!

OBJECTIVES

Overall Objective 1:

The student will be able to discuss the major ideas involved in the life cycle costing of combination solar and conventional heating systems.

Sub-Objectives:

The student will be able to define and discuss the use of each of the following terms:

A. life cycle cost.

B. present value.

C. real annual rate of increase.

D. lifetime present value multiplier.

Overall Objective 2:

The student will be able to compare the life cycle costs of conventional and combination solar/conventional heating systems.

Sub-Objectives:

The student will be able to compute:

A. life cycle solar system costs.

B. annual fuel costs.

C. life cycle fuel cost savings.

D. total life cycle cost savings for solar/conventional heating systems.

1. The total cost of a system's operation over its entire useful life is called the life cycle cost of the system. It includes both the construction cost of the system and the total cost of operating it for as long as it's used.

The total cost of the heat energy supplied by any space or hot water heating system is the system's life cycle cost. In almost all situations the heating system with the lowest life cycle cost will be a combination of a solar heating system and a conventional auxiliary heating system which uses fuel or electricity. A solar system designer's job often includes estimating the amount of heat each part of the system should supply in order to minimize the entire system's life cycle cost.

The life cycle cost of a solar heating system is its construction cost plus total lifetime operating costs which mainly involve maintenance, repairs, and insurance. The life cycle cost of a conventional auxiliary heating system is its construction cost plus total lifetime operating costs which include maintenance, repairs, insurance, and the cost of fuel or electricity.

All combination solar and conventional heating systems experience periods of operation during which the auxiliary conventional system must supply all the required heat. To be able to do that, the auxiliary conventional system must be identical to the conventional system which would have been constructed if no solar system were built. The combination system is really a complete conventional heating system with a solar heating system added. The solar system merely substitutes solar energy for some of the fuel or electricity the other system would have used in its absence.

Adding the solar system decreases the total system's life cycle lost by the cost of the fuel or electricity it replaces over its lifetime. It increases the total system's life cycle cost by the life cycle cost of the solar system itself. A combination system will be more economical than a completely conventional system if the reduction in fuel or electricity costs over its lifetime is greater than the life cycle cost of the solar system. The most economical combination system is the one which has the greatest difference between lifetime fuel or electricity cost savings and life cycle solar system cost.

Give a definition of life cycle cost in your own words and list some of the life cycle costs of a combination solar and conventional heating

system. Check your answers in frame 2.

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2. The life cycle cost of a system is the complete cost of building it and operating it for as long as it's used. Life cycle costs of combination solar and conventional heating systems include their construction costs, total maintenance, repair and insurance costs for their entire operating lives, and total lifetime fuel or electricity costs.

   Suppose you want to decide which of two combination heating systems is the more economical one. They'll probably have the same auxiliary heating system, which will also be a complete conventional heating system. To compare their life cycle costs, all you need to do is compare them both to the life cycle cost of the complete conventional system alone. The one which shows the greatest difference between fuel or electricity cost savings and solar system life cycle cost is the more economical system.

   The procedure we just outlined only requires you to compute the life cycle costs of solar systems, and the cost of the fuel or electricity they replace. You don't have to compute the life cycle cost of the conventional system to compare the costs of the two combination systems.

   Name the two things which must be computed to compare the overall costs of combination solar and conventional heating systems. Check your answers in frame 3.

3. Solar system life cycle costs and lifetime system fuel or electricity cost savings.

The main difficulty in computing lifetime system costs or cost savings is that operating costs, such as maintenance, fuel, or electricity costs, tend to change from year to year. Maintenance, insurance, and repair costs all go up at about the same rate, due to inflation. Fuel and electricity costs are rising at a faster rate than the inflation rate.

One method of comparing totals of annual costs rising at different rates over many years is to compare the present values of the total costs. The present value of a series of annual costs or payments is the amount of money you would have to invest in the first year to yield a total amount equal to the total of the costs or payments at the end of the payment period. If the interest rate on your investment is equal to the annual rate of increase in the costs or payments, their present value is just the first year cost or payment multiplied by the total number of years.

For example, if you put $2000 in the bank this year at an annual interest rate equal to the inflation rate, you could use it to pay annual costs which started at $100 a year and went up at the rate of inflation for 20 years. You'd pay the first $100 out of your $2000 the first year. By the second year, the second $100 in your $2000 would have earned interest equal to the increase in cost, so you could use it plus the interest to pay the second year cost. You could continue the process through the full 20 years, as each $100 of your investment increased to keep pace with the increases in the $100 annual cost. Assuming that you can invest your money at the inflation rate is the simplest way to compute the present value of a series of annual costs which are increasing at the same rate as inflation.

Compute the present value of 30 years of a $50 annual cost which rises at the annual inflation rate. Assume you can invest your money at the annual inflation rate.

Check your answer in frame 4.

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4. $1500.

Suppose the inflation rate were 8%, and you put the $1500 into a bank at 8% annual interest. The first year you'd pay the $50 costs with

the first $50 of your $1500. The second year the costs would be $54 — up 8%. But the second $50 in your $1500 would also have increased to $54. You could use that $54 to pay the second year cost. The third year the cost would go up to $58.32. The third $50 of your original savings would also have increased to $58.32, so you could pay the cost with it. Each $50 in your savings would increase just enough to match the cost when you paid it. All you would need to invest at the beginning would be 30 times $50, or $1500. Go to frame 65.

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5. Computing the present value of a series of payments that rises at the annual inflation rate is easy using the method we just showed you. Computing the present value of a series that increases at a faster rate is a bit more involved.

Suppose, for example, that fuel costs go up at a rate of 15% a year, and the inflation rate is 10%. Say your first year fuel costs savings with a solar system are $200. Your second year fuel cost savings would be $230. The present value of those savings would be the amount you would have had to invest the first year at the inflation rate to get back $230 next year. $230 invested at the inflation rate of 10% would only become $220 in one year, so the present value of the fuel cost savings is more than $200.

$230 is 1.15 times $200, and $220 is 1.1 times $220. The amount you would have to invest this year to get $230 next year is (1.15/1.1) times $200, or $209.09.

The third year fuel savings will be (1.15 (1.15) $200 or $264.50. $200 invested at the inflation rate will grow to (1.1) (1.1) $200 or $242 in two years. The present value of the third year fuel costs savings will be $\frac{(1.15)\ (1.15)}{(1.1)\ \ (1.1)}$ $200 or $\frac{(1.15)^2}{(1.1)^2}$ $200 or $218.60.

The present value of the fourth year savings will be $\frac{(1.15)^3}{(1.1)^3}$ $200 or $228.53.

Each year the present value of the fuel cost savings will go up by a ratio of $\frac{1.15}{1.1}$ or 1.045. The ratio 1.045 corresponds to a 4.5% annual rate of increase in the present value of the fuel cost savings. The annual rate of increase in present value is sometimes called the real annual rate

of increase. For costs rising at the inflation rate, the real annual rate of increase is zero, because the present value of the costs isn't increasing each year.

Suppose the annual inflation rate is 8% and electricity costs are increasing at an annual rate of 15%. Compute the real annual rate of increase of the electricity cost savings resulting from replacing electricity with solar heat. Check your answer in frame 6.

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6. 6.5%.

The annual change in the ratio of the present value of the electricity costs to the present value of costs increasing at the inflation rate will be 1.15/1.08 = 1.065. The real annual rate of increase in electricity cost savings is 6.5%

Suppose the annual inflation rate is 10% and fuel costs are increasing at a rate of 25% per year. Compute the real annual rate of increase of fuel cost savings resulting from replacing fuel with solar heat. Check your answer in frame 7.

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7. 13.6%

The annual change in the ratio of the present value of fuel costs to the present value of costs increasing at the inflation rate will be

(1.25/1.1) = 1.136. The real annual rate of increase in fuel cost savings is 13.6%. Go to frame 8.

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8. The total present value of a series of costs or savings rising at a rate higher than the inflation rate is the sum of the present values for all the years of costs and savings. The sum won't be equal to the first year cost or savings multiplied by the number of years, because each year the present value will increase by a percentage equal to the real annual rate of increase. For example, if the real rate of fuel price increase is 10% per year, and the first year fuel cost savings are $300, the present value of the second year savings is 1.1 times $300 or $330. The present value of the second year savings is 1.1 times $330, or $(1.1)^2$ times $300. The present value of the fourth year savings is $(1.1)^3$ times $300. The total present value of all the savings for 20 years is $300 $[1 + 1.1 + (1.1)^2 + (1.1)^3 + \ldots + (1.1)^{19}]$. The sum in the brackets is called the Lifetime Present Value Multiplier of the $300 first year cost savings. A short formula for the lifetime present value multiplier is

$$\frac{(1.1)^{20} - 1}{1.1 - 1} = \frac{(1.1)^{20} - 1}{.1}$$

If we call the real annual rate of increase i, and write it as a decimal (%/100), the formula for the lifetime present value multiplier for a lifetime of N years is $\frac{(1+i)^N - 1}{i}$

Below is a table of lifetime present value multipliers for various real annual rates of increase and years of system lifetime.

Table of Present Value Multipliers

Percent Real Annual Cost Increase, i	Number of Years, N: 5	10	15	20	25	30
0	5.00	10.0	15.0	20.0	25.0	30.0
1	5.10	10.5	16.0	22.0	28.2	34.8
2	5.20	10.95	17.3	24.3	32.0	40.6
3	5.31	11.5	18.6	26.9	36.5	47.6
4	5.42	12.0	20.0	29.8	41.6	56.1
5	5.53	12.6	21.6	33.1	47.7	66.4
6	5.64	13.2	23.3	36.8	54.9	79.1
7	5.75	13.8	25.1	41.0	63.2	94.5
8	5.87	14.5	27.2	45.8	73.1	113
9	5.99	15.2	29.4	51.2	84.7	136
10	6.10	15.9	31.8	57.3	98.3	164
11	6.23	16.7	34.4	64.2	114	199
12	6.35	17.5	37.3	72.1	133	241

Find the lifetime present value multiplier for a real electricity cost cost increase of 8% per year and a system lifetime of 30 years. Check your answer in frame 9.

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9. The lifetime present value multiplier is 113.

Just look down the 30 year system lifetime column in the table, and find its intersection with the row for an 8% annual rate of cost increase. The number at the intersection is 113, the lifetime present value multiplier.

If fuel costs rose at the rate of inflation, the present value multiplier would just be the number of years in the system lifetime – 30. You can see from this example that the present value of fuel cost savings can be much more than the first year savings times the number of years, if the real annual rate of fuel price increase is higher than inflation. To summarize: the total present value of a series of annual costs is the first year cost multiplied by the lifetime present value multiplier. The lifetime present value multiplier of a series of costs or savings rising at the annual inflation rate is just the number of years of the system lifetime. The lifetime present value multiplier for a cost or saving rising at a rate higher than the inflation rate is the multiplier in the table which corresponds to the real annual rate of increase and the number of years in the system lifetime. For costs for savings rising faster than inflation, the lifetime present value multiplier is always greater than the number of years in the system lifetime. The general formula for the lifetime present value multiplier of a series of costs or savings rising at a real annual rate i (%/100) for a system lifetime of N years is $\frac{(1 + i)^N - 1}{i}$.

Find the lifetime present value multiplier for a cost or savings rising at the inflation rate for a system with a lifetime of 30 years. Then find the multiplier for a cost or savings rising at a real annual rate of 5% for the same system lifetime. Check your answers in frame 10.

10. The lifetime present value multiplier for the cost or savings rising at the inflation rate is just the number of years in the sytem lifetime — 30 in this case. The lifetime present value multiplier for the second cost or savings comes from the table. It's found by going down the column for a 30 year system lifetime and going across the row for a 5% real annual cost increase. The number at the intersection of the row and column is the multiplier. In this case, the multiplier is 66.4. It could also be computed using the formula $\frac{(1+i)^N - 1}{i}$ with i = 05 and N = 30.

Estimating annual insurance and maintenance costs at 1% of the initial cost of a system is very common. It's probably as accurate as any other method. Home insurance rates are about .5% of initial cost or market value, and maintenance will cost about .5% of initial value per year on a good system. Those costs usually increase at a rate about equal to inflation.

Estimating the real annual rate of fuel or electricity cost increase is a guessing game. In recent years the real rate of increase has been as low as 5% and as high as 15%. In the future it will probably be somewhere between those two values. Fuel and electricity costs will almost surely increase at a rate higher than inflation, so the real rate of increase will probably always be greater than zero.

Suppose you build a solar hot water heating system for an initial cost of $1500. The annual insurance and maintenance costs are 1% of the initial cost and you expect them to rise at the inflation rate. You expect to save $100 the first year in fuel costs. You expect fuel costs to rise at a real annual rate of 5%. You expect the system lifetime to be about 20 years. Compute the present value of the lifetime insurance and maintenance costs and the present value of the lifetime fuel savings. Check your answers in frame 11.

11. The lifetime present value multiplier for the insurance and maintenance costs is 20. The multiplier for the fuel cost savings is 33.1 (from the table). The present value of the lifetime insurance and maintenance costs is 20 times $15 (1% of $1500) — $300. The present value of the lifetime fuel savings is 33.1 times $100 — $3310.

If you borrowed $1500 to pay the initial cost, you'd also have to make payments on the loan each year. Let's say the interest rate on the loan is 10%, and let's assume that the inflation rate is about 8%. Mortgage interest rates are generally about 2% above inflation. Under those conditions, your annual payments on the loan would be $176. They would <u>not</u> go up at the inflation rate.

$150 of the first payment would be interest - 10% of the full $1500. Only $26 would go toward paying off the $1500 principal. You could deduct the $150 interest from your taxable income. If you were paying state and local income taxes of 25% of your income, you'd save $37.50 on your total tax bill. The net first year cost of your loan would be $176 payment minus $37.50, or $138.50.

In the second year, $26 of the original principal of $1500 would have been paid off by the first year payment. The interest on the remaining $1474 would be $147.40, and you could save $36.85 on your tax bill by deducting it from your taxable income. Your net second year cost would be $139.15. If you had put $128.84 in the bank the first year at an interest rate of 8% (the inflation rate) you could use it plus the interest on it to pay the net second year loan cost.

The net third year loan cost would be $139.87, because your income tax deduction would be a little smaller. Putting only $119.82 in the bank at 8% the first year would enable you to pay the third year cost, because the money would have earned $20.05 in interest in two years.

Things would continue in the same fashion for the entire 20 years. The result would be that if you put only $1452 in the bank the first year, you'd be able to pay back the entire loan by using the interest on it plus your small annual tax savings.

In almost all cases, things work out that way. That makes it easy to get a rough estimate of the <u>present value</u> of the total loan cost. It's

almost always very close to the amount of the loan. Go to frame 12.

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12. If you pay cash for a solar system, the present value of its initial cost is obviously the amount of cash you pay. If you pay part of the initial cost with a loan, the total loan cost will have a present value very close to the amount of the loan. The present value of the loan and the down payment will be very close to the down payment plus the amount of the loan. In both cases, the present value of the system's initial cost will be about equal to the cash price.

All that means is that you don't have to go through a complicated computation to find the present value of the initial cost of a solar system, even if part of the cost is paid with a loan. You can just act as if the system were bought with cash, and your estimate will be very accurate.

Now let's use the first year fuel or electricity cost savings, annual maintenance and insurance costs, and initial construction cost to compare the total life cycle cost of a combination solar and conventional heating system to the cost of a completely conventional system. Let's say the conventional system is an electric hot water heating system, and its annual electricity cost is $133. You plan to add a solar hot water heater at an initial construction cost of $1500. Annual maintenance and insurance costs will be about 1% of the initial cost, or $15 the first year.

They'll increase at the annual inflation rate. Fuel costs will go up at a real annual rate of 6%. The solar system will provide 75% of the required heat. The total system lifetime is estimated at 20 years. Compute the total life cycle cost savings of the combination system compared to the life cycle cost of the conventional system. Check your result in frame 13.

13. You need to find the life cycle solar system cost and subtract it from the life cycle fuel cost savings. The present value of the initial cost is $1500, whether or not you take out a loan to pay part of the initial cost. The lifetime present value multiplier of the annual maintenance and insurance cost is 30, because it rises with inflation. The present value of those annual costs is $15 times 20, or $300. The present value of the total life cycle cost of the solar system is $1500 plus $300, or $1800.

The fuel cost saving in the first year will be 75% of $133, or about $100. The lifetime present value multiplier of the fuel cost will be 36.8. The total life cycle fuel cost savings will be 36.8 times $100, or $3680.

The total life cycle cost of the 75% solar system will be $3680 minus $1800, or $1880 less than the total life cycle cost of the completely conventional system.

Let's do another one. Suppose you could build a solar space heating system at an initial cost of $10,000. It will provide 50% of the total heat required by your house over a heating season. The total fuel cost for a heating season is $600. You estimate annual insurance and maintenance costs at 1% of the initial cost of the system, and you guess they'll rise at the inflation rate. You guess that fuel costs will rise at a real annual rate of about 4%. You expect the system to last 30 years. Compute the life cycle cost savings of the combination solar and conventional system compared to the life cycle cost of a completely conventional system. Check your answer in frame 14.

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14. The present value of the solar system's initial cost is about $10,000. The annual maintenance and insurance costs are 1% of $10,000, or $100. The lifetime present value multiplier of those costs is 30, because they'll rise at the inflation rate. Their total present value is 30 times $100 or $3000. The total life cycle solar system cost is $13,000.

The first year fuel cost savings will be 50% of $600, or $300. The lifetime present value multiplier for the annual fuel cost is 56.1. The total life cycle fuel cost savings are 56.1 times $300, or $16,830. The total life cycle cost savings are the fuel cost savings, $16,830, less the life cycle cost of the solar system, $13,000. The savings are $3830. Go to frame 15.

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15. You can see it's not difficult to estimate the life cycle cost savings of solar systems if you have estimates of their initial costs, annual maintenance and insurance costs, the real annual rate of fuel or electricity cost increases, and the first year fuel or electricity cost savings. Pricing materials and labor during the design process is the only way to estimate the initial cost of a solar system. Annual maintenance and insurance costs will probably be about 1% of the initial cost. The real annual rate of fuel or electricity cost increases is anyone's guess, but will probably be between 5 and 10 percent. You can try several estimates and see how they work out. It's not much extra work.

Estimating first year fuel or electricity cost savings involves the least guesswork. You compute the first year cost of the fuel or electricity the auxiliary heating system would use to supply all the required heat. Then you multiply by your estimate of the fraction (%/100) of the heat the solar system will supply. The result is the first year fuel or electricity cost savings due to the operation of the solar system. Go on to frame 16.

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16. To compute the cost of fuel or electricity used by the auxiliary system, you need to know the cost of fuel or electricity in dollars per million BTU of heat value, the efficiency of the auxiliary heating system at turning fuel or electricity into heat, and the total heat required.

The total heat required can be computed using one of the methods you learned in module 3 and reviewed in module 5. The total heat value of the fuel or electricity required is the total heat required <u>divided</u> by the decimal efficiency of the auxiliary heating system.

The total cost of the required heat is the cost of the fuel or electricity per million BTU of heat value multiplied by the total heat value of the required fuel or electricity in millions of BTU.

The computation breaks down into four steps:

1. Compute the total heat required in millions of BTU using one of the methods you learned in module 3.
2. Divide the required heat by the decimal (%/100) efficiency of the auxiliary system. The result is the heat value of the required fuel or electricity in millions of BTU.

3. Compute the cost of the fuel or electricity per million BTU of heat value.
4. Multiply the fuel or electricity cost per million BTU of heat value (step 3) by the heat value of the required fuel or electricity in millions of BTU (step 2).

Go on to frame 17.

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17. Space or hot water heating systems which burn fuel are much less than 100% efficient. Systems which burn oil or natural gas usually have efficiencies of only 60%. Good wood stoves have efficiencies of only 40 to 60%.

Electric heating systems are usually assumed to be 100% efficient. They aren't. However, they waste much less heat than fuel burning systems. Assuming they're 100% efficient is a fairly accurate way to estimate electricity costs.

Suppose your house requires 60 million BTU of heat to heat it for a year. Compute the heat value of electricity, fuel oil, natural gas, or wood required to produce the required heat. Assume a wood stove would have an efficiency of 50%, an oil or gas burning system would have an efficiency of 60%, and an electric heating system would have an efficiency of 100%. Check your answers in frame 19.

18. The heat value of the required fuel is the required heat divided by the decimal (%/100) efficiency of the heating system. For electricity, the decimal efficiency is 100/100, or 1, and the required heat value is 60 million BTU divided by 1, or 60 million BTU. For fuel oil or natural gas, the decimal efficiency is 60/100 or .6, and the required heat value is 60 million BTU divided by .6, or 100 million BTU. For wood the decimal efficiency is 50/100 or .5, and the required heat value is 60 million BTU divided by .5, or 120 million BTU.

Here's a formula to help you remember:

$$\text{Heat value of fuel or electricity} = \frac{\text{heat required}}{\text{decimal efficiency}}$$

A shorthand for millions of BTU is MBTU.

Here's another one:

You'll need 20 MBTU of hot water heat each year. Compute the heat values of the wood, fuel oil, natural gas, and electricity required to produce the heat. Assume the efficiencies of the heating systems are the same as the ones given in frame 17. Check your answers in frame 19.

19. The answers are

electricity: 20 MBTU

oil or gas: 33.3 MBTU

wood: 40 MBTU

If you're having trouble with these computations, get help from your instructor. Make sure you can do them, then go on to frame 20.

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20. Fuel and electricity costs usually aren't given in dollars per million BTU of heat value ($/MBTU). They're given in dollars per cord of wood, cents per therm of natural gas, cents per barrel of fuel oil, and cents per kilowatt-hour of electricity.

You need to know the number of BTU of heat energy in a cord of wood, therm of natural gas, barrel of fuel oil, and kilowatt-hour of electricity, in order to compute their costs in $/MBTU. A cord of soft wood like douglas fir will have a heat value of about 10 MBTU. Hard wood, like oak, has a heat value of about 20 MBTU per cord. The standard amounts of electricity and other fuels have heat values of less than a million BTU (1 MBTU).

A therm of natural gas has a heat value of about 100,000 BTU, or .1 MBTU. (100,000 divided by 1,000,000) a gallon of fuel oil has a heat value of about 140,000 BTU, or .14 MBTU (140,000/1,000,000). A kilowatt-hour (KW-Hr.) of electricity has a heat value of 3413 BTU, or .003413 MBTU (3413/1,000,000).

We can write these facts as <u>conversion factors</u> between the commonly used units and MBTU of heat value.

Here they are:

soft wood: 1 cord/10 MBTU

hard wood: 1 cord/20 MBTU

natural gas: 1 therm/.1 MBTU

fuel oil: 1 gallon/.14 MBTU or 1 Gal./.14 MBTU

electricity: 1 Kw-Hr./.003413 MBTU

To find the costs of the various fuels and electricity in dollars per million BTU ($/MBTU), you just multiply the price in dollars per common unit by the proper conversion factor. Here's an example:

Say electricity costs 3 cents ($.03) per kilowatt-hour. That's $.03/Kw-Hr. The cost of electricity in $/MBTU is then $.03/Kw-Hr. times 1 Kw-Hr./.003403 MBTU or

electricity cost = ($.03/Kw-Hr.) (1 Kw-Hr./.003413 MBTU)

$$= \frac{\$.03}{.003413} \text{ /MBTU}$$

electricity cost = $8.79/MBTU

Suppose natural gas costs 33 cents ($.33) a therm. Compute the cost of natural gas per MBTU of heat value. Check your answer in frame 21.

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21. Multiply $.33/therm by 1 therm/.1 MBTU:

natural gas cost = ($.33/therm) (1 therm/.1 MBTU)

$$= \frac{\$.33/\text{MBTU}}{.1}$$

natural gas cost = $3.30/MBTU

Suppose hard wood costs $50 a cord. Compute the cost of wood per MBTU of heat value. Check your answer in frame 22.

22. Multiply $50/cord by 1 cord/20 MBTU:

hard wood cost = ($50/cord) (1 cord/20 MBTU)

$$= \frac{\$50/\text{MBTU}}{20}$$

hard wood cost = $2.50/MBTU

One more. Suppose fuel oil costs 40 cents a gallon. Compute the fuel oil cost in $/MBTU of heat value. Check your answer in frame 23.

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23. Fuel oil cost = $2.86/MBTU

If you missed it, go back over frames 20 through 22. When you can do the computation, go on to frame 24.

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24. Let's put together all the steps in computing the first year fuel cost. Suppose your house will require 75 MBTU of heat to keep it warm all year. Your auxiliary heating system will be a wood stove (50% efficient). You expect to pay $40 a cord for soft wood (1 cord/10 MBTU). Compute the total first year fuel cost for your house, assuming the wood heat system will supply all the heat. Look back at frame 16 if you have trouble remembering the steps. Check your work in frame 25.

25. Step 1 of the computation has already been done for you. The required heat is 75 MBTU. The heat value of the required fuel is 75 MBTU divided by .5 — the decimal efficiency of the wood stove. It comes out 150 MBTU. The cost of the fuel is ($40/cord) (1 cord/10 MBTU) = $4/MBTU. The total first year fuel cost is ($4/MBTU) 150 MBTU = $600.

Here's another one. Your hot water heat requirement for a year will be about 25 MBTU. Your auxiliary hot water heater will use electricity at $.025/Kw-Hr. Compute the first year electricity cost. Check your work in Frame 25.

26. The total heat value of electricity required is 25 MBTU. The electricity cost per MBTU is ($.025/~~Kw-Hr.~~) (1 ~~Kw-Hr.~~/.003413 MBTU) = $7.32/MBTU. The first year electricity cost is $183.

The total heat value of electricity required is the same as the total heat required, because the decimal efficiency of the electric heating system is 1 (100/100). Find the first year cost of a 25 MBTU heat requirement using wood heat at $65 per hardwood cord and 50% wood stove efficiency. A cord of hardwood has a heat value of 20 MBTU. Check your answer in frame 27.

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27. The required heat value of wood is 25 MBTU/.5 = 50 MBTU. The cost per MBTU of heat value is ($65/~~cord~~) (1 ~~cord~~/20 MBTU) = $3.25/MBTU. The first year fuel cost is ($3.25/MBTU) (50 MBTU) = $162.50. The cost for 25 MBTU of heat

using electricity at $7.32/MBTU was $183. The higher efficiency of the electric heating system almost made up for the higher cost of electricity per MBTU of heat value.

Let's now review the procedure for computing the required heat as part of a complete computation of first year heat costs. Suppose you live in Portland, which has about 4600 degree-days during the heating season. The heat loss multiplier of your house is 600 BTU/^{o}F.-Hr. Compute the total heat required for the heating season. Check your result in frame 28.

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28. You need to use the formula

Q = (24 Hr./Day) (H) (degree-days)

Q = (24 Hr./Day) (600 BTU/Hr.-^{o}F.) (4600 ^{o}F.-Day)

Q = 66,240,000 BTU

Q = 66.24 MBTU (66,240,000/1,000,000)

Now suppose you'll use a natural gas auxiliary heating system. The cost of the natural gas is 35 cents a therm. You expect that the heating system efficiency will be 60%. Compute the first year heating cost. Check your answer in frame 29.

29. The first year heating cost is $386.40. If you had trouble, review frames 20 through 27, and get help from your instructor if you need it. When you get our answer, go on to frame 30.

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30. O.K., now all at once: You live in Corvallis. There are 4000 heating season degree-days. Your house has a heat loss multiplier of 700 BTU/Hr.-^{o}F. You plan to use an oil burning auxiliary heating system. It's efficiency is estimated at 60%. Fuel oil costs 40 cents a gallon. The heat value of a gallon of fuel oil is 140,000 BTU (.14 MBTU). Compute the first year fuel cost for the auxiliary system. Check your answer in frame 31.

31. Heat required: 67.2 MBTU
Heat value of fuel oil required: 112 MBTU
Fuel oil cost: $2.86/MBTU
First year fuel cost: $320

A 50% solar heating system would save you $160 the first year ($320 times .5). Suppose the solar system cost $8000. You expect fuel costs to increase at a real annual rate of 8%. You'll have normal annual insurance and maintenance costs. The system lifetime is expected to be 30 years. Compute the present value of life cycle cost savings that result from adding the solar system. Check your work in frame 32.

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32. The present value of the initial cost is $8000. The annual insurance and maintenance costs will be 1% of $8000, or $80, and their total present value will be $2400. The present value of the life cycle cost of the solar system is $8000 plus $2400 or $10,400. The lifetime present value multiplier of the annual fuel cost savings is 113. The total present value of the life cycle fuel cost savings is $18,080. The present value of the life cycle savings resulting from installing the solar system is $18,080 - $10,400 = $7680.

Here's another one. Suppose your family uses 100 gallons of hot water a day. The temperature of the water coming into the hot water heater is 50 ^{o}F., and you want the temperature of the hot water to be 120 ^{o}F. Calculate the amount of heat you'll require to heat your hot water for a year. Check

your answer in frame 33.

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33. Use $Q = VC_V\Delta T$ with V = 100 gallons, C_V = 8.34 BTU/Gal.-^{O}F., ΔT = 120 ^{O}F. - 50 ^{O}F. = 70 ^{O}F., for one day's heat. Multiply by 365 to get the heat required for a year. A day's heat requirement is 58,380 BTU, or .05838 MBTU. (58,380/1,000,000). A year's heat requirement is 21.3 MBTU.

Suppose you were going to use electric heat at $.03/Kw-Hr. to heat the hot water. You expect the real annual rate of fuel cost increase to be 6%. You decide to build a solar system to provide 75% of the required heat. It will cost $1000 and last 20 years. Compute the life cycle cost savings resulting from installing the solar system. Don't forget insurance and maintenance. Check your results in frame 34.

34. Total required heat: 21.3 MBTU

Heat value of required electricity (100% efficiency): 21.3 MBTU

Electricity cost: $8.79/MBTU

First year electricity cost: $187.23

First year electricity cost saving: $140.42

Lifetime present value multiplier for fuel cost: 36.8

Present value of lifetime fuel cost savings: $5167.46

Present value of initial cost: $1000

Annual insurance and maintenance costs: $10

Present value of life cycle insurance and maintenance costs: $200

Present value of solar system life cycle cost: $1200

Life cycle cost savings: $5167.46 − $1200 = $3967.46

You've now had several opportunities to try your hand at computing life cycle cost savings for solar systems. The computations are pretty simple, if a bit lengthy.

However, we've left out some tax considerations that could affect the life cycle cost savings. The first is additional property tax due to construction of the solar system. The second is credit on state and federal income tax for installation of an energy conserving system. There's no federal income tax credit, but Oregon allows a total state income tax credit of 25% of the initial cost or $1000, whichever is less, on any device which saves 10% or more of the total energy used in a home. In Oregon, solar systems are exempt from property tax. Go on to frame 35.

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35. Property taxes and income tax credits can introduce additional life cycle costs and savings which affect the total life cycle cost of the solar system. The present values of property taxes and income tax credits are computed most simply by assuming that taxes will rise at the general inflation rate. Tax credits taken after the first year have present values less than their dollar values by amounts corresponding to the inflation rate. Increased property taxes in later years also have present values which are reduced by inflation. Those costs and savings can be estimated in ways similar to those you've used to estimate maintenance and insurance costs.

You should now have a pretty good idea of how to compute costs and savings for solar systems The post-test will give you some chances to try out the methods you've just learned. See what you can do.

Post-Test

1. Explain the idea of a life cycle cost and discuss how it is used to compare cost savings for combination solar/conventional heating systems.

2. Explain the idea of present value, and discuss how it is used in computing life cycle costs.

3. Explain the idea of a real annual rate of increase.

4. Explain what a lifetime present value multiplier is and how it is used to compute lifetime system costs.

5. You want to compare the life cycle cost of a combination solar/electric hot water heating system to that of a completely electric system. You expect to use 50 gallons of hot water a day, which will be heated from 50 ^{o}F. to 120 ^{o}F. by the heater. Electricity costs $.03/Kw-Hr. Compute the annual fuel cost for the completed electric system.

6. The solar system part of the solar/electric hot water heating system in question 5 will cost $1000. It will have normal insurance and maintenance costs over its 20 year life. You expect the solar system to supply 75%

of the required hot water heat.

You think the real annual rate of fuel cost increase will be 4% per year. Compute the first year fuel cost savings, total fuel cost savings, and the life cycle cost savings of the combination solar/electric system. Ignore the state income tax credit.

7. You live in an area where there are 5500 heating degree-days during the heating season. You own a wood-heated house with a heat loss multiplier of 800 BTU/Hr.-^{o}F. You pay $50/cord for hardwood with a heat content of 20 MBTU/cord. Your wood stove has an efficiency of 40%. Compute your annual heating costs.

8. You decide to build a solar heating system to help heat the house in question 7. It will collect 50% of the required heat. It will have an initial cost of $8000, and normal maintenance and insurance costs. You expect fuel prices to go up at a real rate of 6% a year. The system will last 30 years. Compute the first year fuel savings of the combination solar/wood heating system. Ignore the state income tax credit.